PROJECT REPORT

On

REACTIVE POWER COMPENSATION USING FACT DEVICES

Under Guidance

Of

Prof. DIPTI PATRA

Submitted

By

AKASH KUMAR SAH (111EE0228)

BUDHI MAN MOKTAN (111EE0563)

Department of Electrical Engineering

National Institute of Technology

Rourkela-769008, Orissa

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AKASH KUMAR SAH (111EE0228)

BUDHI MAN MOKTAN (111EE0563)

CERTIFICATE

This is to certify that the Project entitled "**STUDY OF REACTIVE POWER COMPENSATION USING FACT DEVICES**" presented by Akash Kumar Sah and Budhi Man Moktan in fractional satisfaction of the prerequisites for the honor of Bachelor of Technology Degree in Electrical Engineering at National Institute of Technology, Rourkela (Deemed University), is a valid work completed by them under my watch and direction.

Date :

Place : Rourkela

(Prof. Dipti Patra)

Department of Electrical Engineering

NIT Rourkela

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ABSTRACT

To repay the reactive power misfortunes in the transmission line and any place in the electrical influence framework, we have completed the writing survey of the different papers and embraced the distinctive procedures to defeat this issue. We have utilized the shunt and series arrangement strategies, in which the compensator like capacitor will be given in parallel and in series to the inductive load. Since there is dependably a voltage and current transient upon the changing the capacitor steps. Henceforth we adopted the FACTS (Flexible AC Transmission Systems) gadgets to beat the responsive force remuneration issue. The studies for the different FACTS gadgets were completed and we discovered the STATCOMs (Static Synchronous Compensators) is the present day and the most productive approach to conquer the responsive force pay. The different strategies were done for the STATCOMS. The genuine investigation were completed in MATLAB and its scientific outflow was inferred utilizing diverse routines for calculation.

Study of FACTS devices like STATCOM and SVC is being presented in this paper. These devise have allowed as to compensate reactive power and mitigate problems occurring in transmission lines. This thesis present the analysis of Static Synchronous Compensator for single phase AC transmission line and also compared the results with Static VAR Compensator and tabulated their differences. Also the analysis of STATCOM for three phase AC transmission line has also been performed accordingly. Principle of operation of Static Synchronous Compensator and PWM techniques have also been employed in simulation of STATCOM, which are briefly presented in this paper. We have also done basic mathematical formulation for STATCOM. These thesis basically present the operation of STATCOM to compensate reactive power when connected to single or three phase AC transmission lines.

CHAPTER - 1

1. INTRODUCTION

Generation of power and its transmission is a perplexing procedure, obliging waging of numerous components in power system when coupled to amplify the yield. One of the principle parts to form a significant part is the reactive power in the transmission system. It is obliged to keep up the voltage to convey the dynamic power in the lines. Burdens like engine burdens and different burdens oblige different reactive power in there operation. To enhance the execution of air conditioning force systems, we have to deal with this reactive power in a proficient way and it is called as reactive power remuneration. There are two viewpoints to the issue of reactive power remuneration: load remuneration and voltage support. Load remuneration comprises of change in force component, adjusting of genuine force taken from the supply, good voltage regulation, and so on of extensive changing burdens. Voltage bolster comprises of decrease of voltage change in a transmission line. These types compensation can be realized in two way: series and shunt compensation. These adjust the parameters of the framework to give improved VAR compensation. A shunt compensation is one where capacitors are employed in parallel with the transmission line and act like a synchronous condenser and absorb or supply reactive power. A series is one where inductor or capacitor are employed in series to supply required power. Mostly shunt compensation are employed nowadays in FACT devices.

Flexible AC Transmission (FACT) devices are static equipments which helps in not only for compensating reactive power but also control one or more AC transmission parameters. Flexible AC Transmission Devices includes Static synchronous compensator, Thyristor switched reactor, Static synchronous series compensator, Thyristor switched capacitor, Thyristor switched series reactor. All these equipment are static instruments, so there is no dynamic effect. Static synchronous compensator (STATCOM) basically includes a DC power capacitor, a converter (may act as rectifier when reactive power is being absorbed and as an inverter when reactive power is being supplied to the transmission system), step up transformer, series inductors etc.

1.1 MOTIVATION

The following are the motivation for carrying out this project

1. Improvement of the quality of the power.
2. Improvement of system power factor.
3. Reduction of the losses in the network.
4. Shirking of penalty charges for the over the top use of the reactive power particularly in industry where they utilize expansive induction motors.
5. Reduction of cost and generate higher revenue for the customers.
6. Improvement of the voltage regulation of the power system.
7. Increase the power availability.

1.2 LITERATURE SURVEY

First we have conducted various searches on how to compensate reactive and then by using what we can do so efficiently. We have concluded that there are numerous equipments under FACT devices which helps in compensating reactive power. Then after going through various papers and surveys, we concluded that Static Synchronous Compensator compensates reactive power in most efficient way. STATCOM is a very important controller under FACTS devices and it helps in controlling voltage. First STATCOM which was put in operation was in Japan during 1980 which utilizes power commutated thyristors and works at 20MVar [10]. KEPCO and Mitsubishi Motors introduced a ±80MVar STATCOM during 1991.

STATCOM have numerous forms, however in most reasonable applications it utilizes the inverter which can likewise be known as a Voltage Source Inverter (VSI) in 3-stage design as the essential square. The essential hypothesis of VSI is to create a situated of controllable 3-stage yield voltages/ streams at the crucial recurrence of the AC transport voltage from a DC info voltage source, for example, a charged capacitor or a DC vitality supply gadget. By fluctuating the extent and stage edge of the yield voltage and current, the framework can trade dynamic/responsive power between the DC and AC transports, and direct the AC bus voltage.

1.3 CHALLENGES

In the tenure of carrying out the project, we faced many challenges. However because of the constant guidance from our project supervisor and help from the resource person we could overcome every challenges we faced. Off course we came across many minor and major challenges, out of which some are mentioned bellow and discussed how we overcome each challenges. While doing the analysis of the STATCOM in the Multisim. We were not able to connect the three phase transformer to the power system, to which we have to supply the reactive power drawn by the inductive load. But after doing the polarity test for the transformer, we could overcome this challenge. Initially after completing complete circuit for the converter, this converter is not acting as inverter, when reactive power to be supplied to the system and the converter is not acting as rectifier, when excess reactive power to be drawn from the power system when capacitive load is connected to the power system. But after consulting the resource person, we knew all thyristors, which we have used in the converter should be triggered with PWM (pulse width modulation). The problem that we encounter was the whole STATCOM output. We were not able to get the complete sinusoidal three phase output from the STATCOM. Since after doing trial and error method by changing the capacitor value at the DC side of the converter and correspondingly changing the inductor and setting capacitor initial value to 50 V. we could obtain the optimum value of capacitor and inductor after which we could obtain the complete three phase sinusoidal wave from the AC side of the converter. Hence the STATCOM is now ready to draw and supply the reactive power to the power system.

1.4 PROBLEM STATEMENT

The impedance of transmission lines and the requirement for lagging VAR by most machines in a creating framework brings about the utilization of reactive power, in this way influencing the steadiness furthest reaches of the framework and in addition transmission lines. Pointless voltage drops lead to expanded misfortunes which needs to be supplied by the source and thus prompting blackouts in the line because of expanded weight on the framework to convey this fanciful influence. Therefore we can gather that the remuneration of reactive power mitigates every one of these impacts as well as aides in better transient reaction to blames and aggravations. As of late there has been an expanded concentrate on the systems utilized for the pay and with better gadgets included in the innovation, the remuneration is made more viable. It is all that much obliged that the lines be diminished of the commitment to convey the receptive force, which is better given close to the generators or the heaps. Shunt compensation can be introduced close to the load, in a dispersion substation or transmission substation.

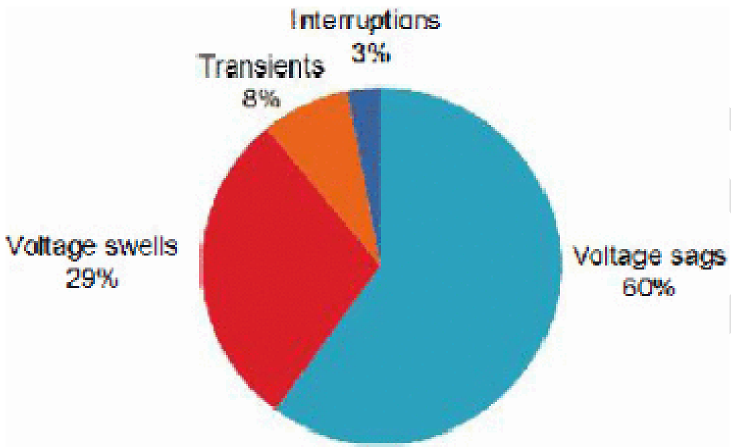

Figure 1 : Percentages of problems in power quality

1.5 THESIS OBJECTIVES

The primary objective of this project is to compensate the reactive power via Flexible AC Transmission System Devices. Out of many FACTS devices, we have streamline on the STATCOM (Static Synchronous Compensator) and the SVC (Source Voltage Converter). Since these two techniques of compensating the reactive power is recent and most efficient way of compensating the reactive power.

1) First objective is to theoretically understand the reactive power compensation through shunt and series compensation and basic mathematical formulas
2) To compensate the reactive power in single phase AC system by both STATCOM and SVC.
3) To do the analysis of STATCOM and SVC in single phase AC system in Simulink.
4) To do the comparison of STATCOM and SVC.
5) To compensate the reactive power in three phase AC system by using STATCOM

CHAPTER - 2

2. GENERAL COMPENSATION METHODS

2.1 SHUNT COMPENSATION

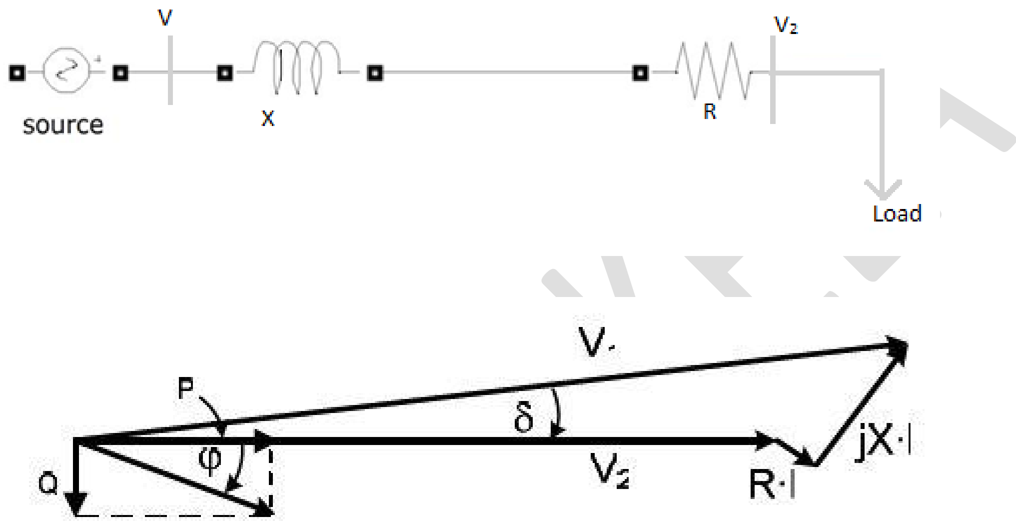

Figure 2: Circuit and Phasor Diagram without Compensation

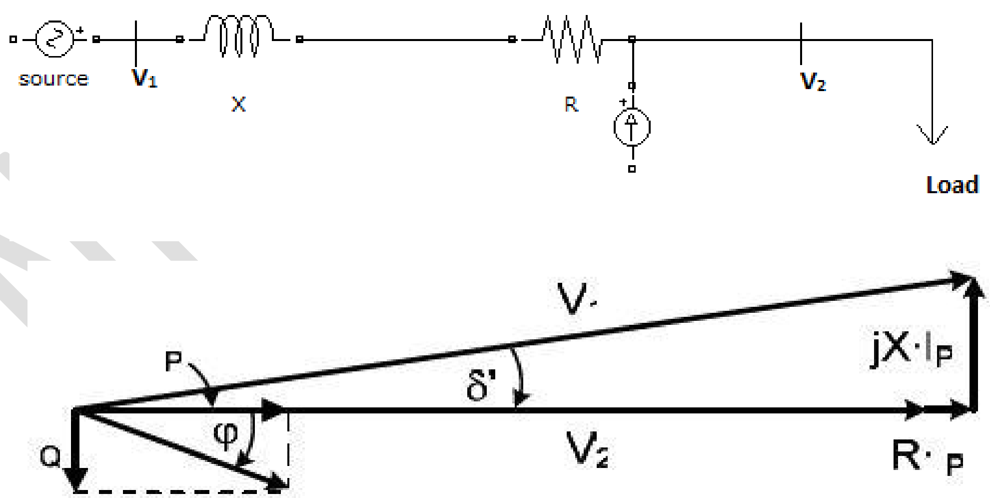

Figure 3: Circuit and Phasor Diagram after Compensation

In figure 2 we have a source voltage V_1, an electrical cable and a load. The figure 2 shows the phasor diagram of transmission system when no compensation have been implemented. Since the load is inductive current lags the voltage V_2 by some angle. Current has two components, one is responsible for active power and other is responsible for reactive power. Current along P is in phase with voltage V_2. Since the load is inductive in nature, current and voltage waveform are not in same, hence it will draw reactive power, which we need to compensate. This could be achieved possibly in three ways: 1) A voltage source. 2) A current source. 3) A capacitor.

For this situation, figure 3, we are employing a current source to compensate reactive power component Iq. Thusly the voltage regulation of the framework is enhanced and the responsive current part from the source is diminished or just about disposed of. This is if there should arise an occurrence of lagging pay. For leading remuneration, we require an inductor.

Thusly, we can conclude that current source method or a voltage source method, both can work shunt compensation, whatever the load, i.e, lagging or leading. The primary focal points being the responsive force created is free of the voltage at the purpose of connection.

2.2 SERIES COMPENSATION

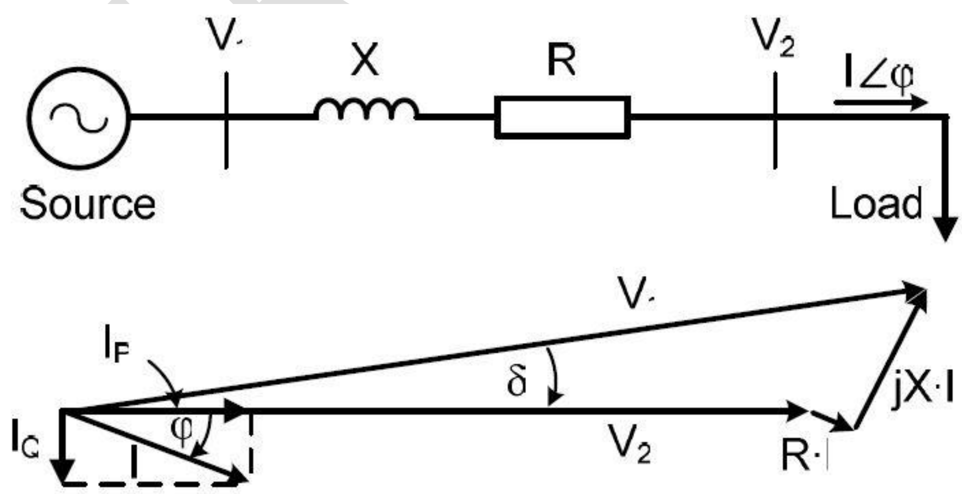

Figure 4: Circuit and Phasor Diagram without Compensation

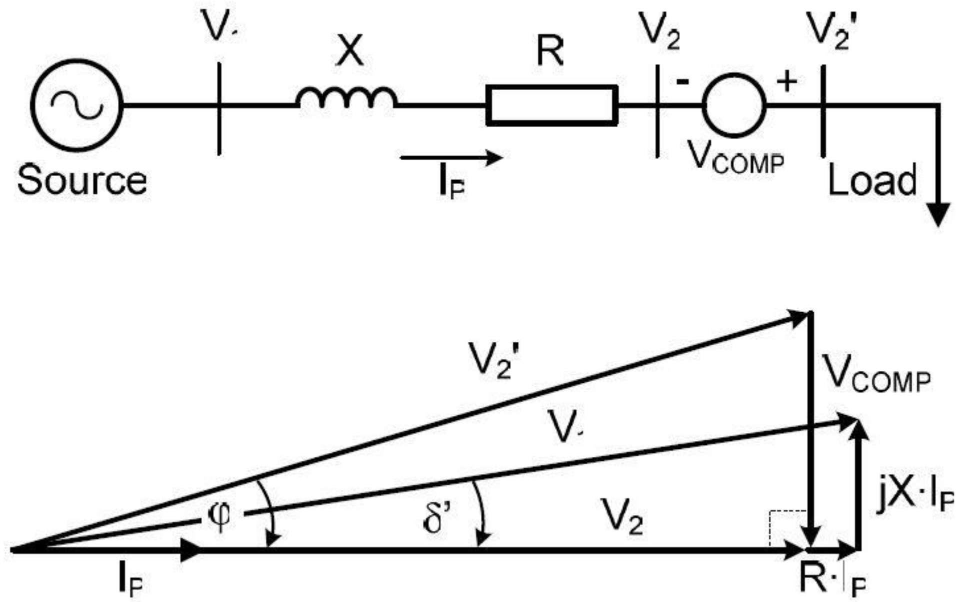

Figure 5: Circuit and Phasor Diagram after Compensation

Series arrangement pay can be executed like shunt remuneration, as we can see that clearly in Fig 5. We can look that the outcomes which are acquired by series compensation via a voltage source and it is acclimated to have solidarity force component at V_2. However series arrangement remuneration procedures are unique in relation to shunt pay systems, as capacitors are utilized generally for arrangement pay methods. For this situation, the voltage V_{comp} has been included between the line and the heap to change the edge V_2'. Presently, this is the voltage at the heap side. With legitimate change of the extent of V_{comp}, solidarity force component can be come to at V_2.

2.3 STATCOM

Static Synchronous Compensator is one of the static component device and comes under the family of FACTS devices. It can absorb or supply reactive power in the single or three phase AC systems. A transmission network reactive power can be compensated using Static Synchronous Compensator. It also helps in preventing fluctuations in the transmission system like sudden voltage increase (voltage sag), sudden voltage decrease (voltage sag), transients etc.

A STATCOM comprises of a three phase inverter utilizing SCRs, MOSFETs or IGBTs, a DC capacitor (which when charging will absorb reactive power and while discharging will supply reactive power), a connection reactor whose purpose is to link the inverter output to the AC supply side, channel parts to channel out the high recurrence segments because of the PWM inverter. From the DC side capacitor, a three stage voltage is produced by the inverter. This is synchronized with the AC supply. The connection inductor interfaces this voltage to the AC supply side. This is the essential standard of operation of STATCOM.

A D-STATCOM, which is schematically portrayed in Fig. 6 comprises of a two level voltage source converter (VSC), a dc vitality stockpiling gadget, a coupling transformer joined in shunt to the dispersion organize through a coupling transformer. Such setup permits the gadget to retain or produce controllable dynamic and receptive force. The D-STATCOM has been used predominantly for regulation of voltage, remedy of force component and end of current sounds. Such a gadget is utilized to give consistent voltage regulation utilizing a by implication controlled converter. In this venture, the D-STATCOM is utilized to manage the voltage at the purpose of association.

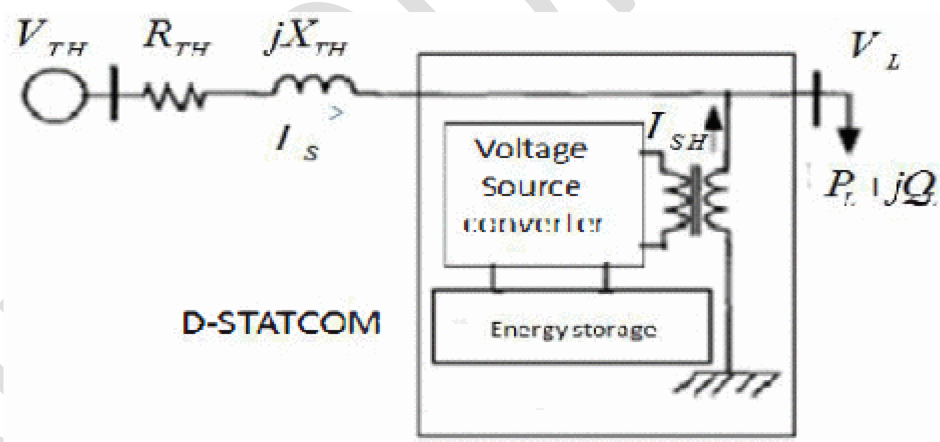

Figure 6: Basic model of a Distribution STATCOM

2.4 MATHEMATICAL FORMULATION

Instantaneous power in a lagging circuit can be represented by:

$$p = V_{\max} I_{\max} \cos wt \cos(wt - \theta)$$

$$p = \frac{V_{\max} I_{\max}}{2} \cos\theta (1 + \cos 2wt) + \frac{V_{\max} I_{\max}}{2} \sin\theta \sin 2wt$$

The reactive power can be represented by:

$$\frac{V_{\max} I_{\max}}{2} \sin\theta \sin 2wt$$

Where:

p	= Instantaneous power
$V_{\max}$	= Maximum voltage
$I_{\max}$	= Maximum current
w	= Angular frequency
	= 2*pi*f where f is the frequency.
t	= Time period
θ	= Angle between voltage and current

From here, we can conclude that the time period of the instantaneous reactive power is two times the normal system frequency and have a zero average value and its maximum value can be represented as follows:

$$Q = |V||I| \sin\theta$$

From the Figure 6, current from the inverter I_{SH} adjusts the voltage increase by varying the voltage drop across the Z_{TH}. Value of shunt current can be controlled by controlling the value of output supplied by inverter.

The shunt injected current I_{SH} can be written as,

$$I_{SH} = I_L - Is \qquad (1)$$

Where, $I_S = \dfrac{V_H - V_L}{Z_{TH}}$ (2)

Therefore,

$$I_{SH} = I_L - I_S = I_L - \frac{V_H - V_L}{Z_{TH}} \tag{3}$$

Or,

$$I_{SH}\angle\eta = I_L\angle-\theta - \frac{V_{TH}}{Z_{TH}}\angle(\delta-\beta) + \frac{V_L}{Z_{TH}}\angle-\beta \tag{4}$$

The complex power of the D-STATCOM,

$$S_{SH} = V_L I_{SH}^{*} \tag{5}$$

It is important to note that the efficiency of the D-STATCOM in balancing voltage sag depends on the value of system impedance (Z_{TH}). When the shunt current or inverter output current (I_{SH}) is kept in required phase with V_L, the desired voltage balancing can be achieved without injecting any active power into the system.

CHAPTER - 3

3. ANALYSIS OF STATCOM AND SVC FOR SINGLE PHASE AC SYSTEM

3.1 STATCOM ANALYSIS USING SIMULINK

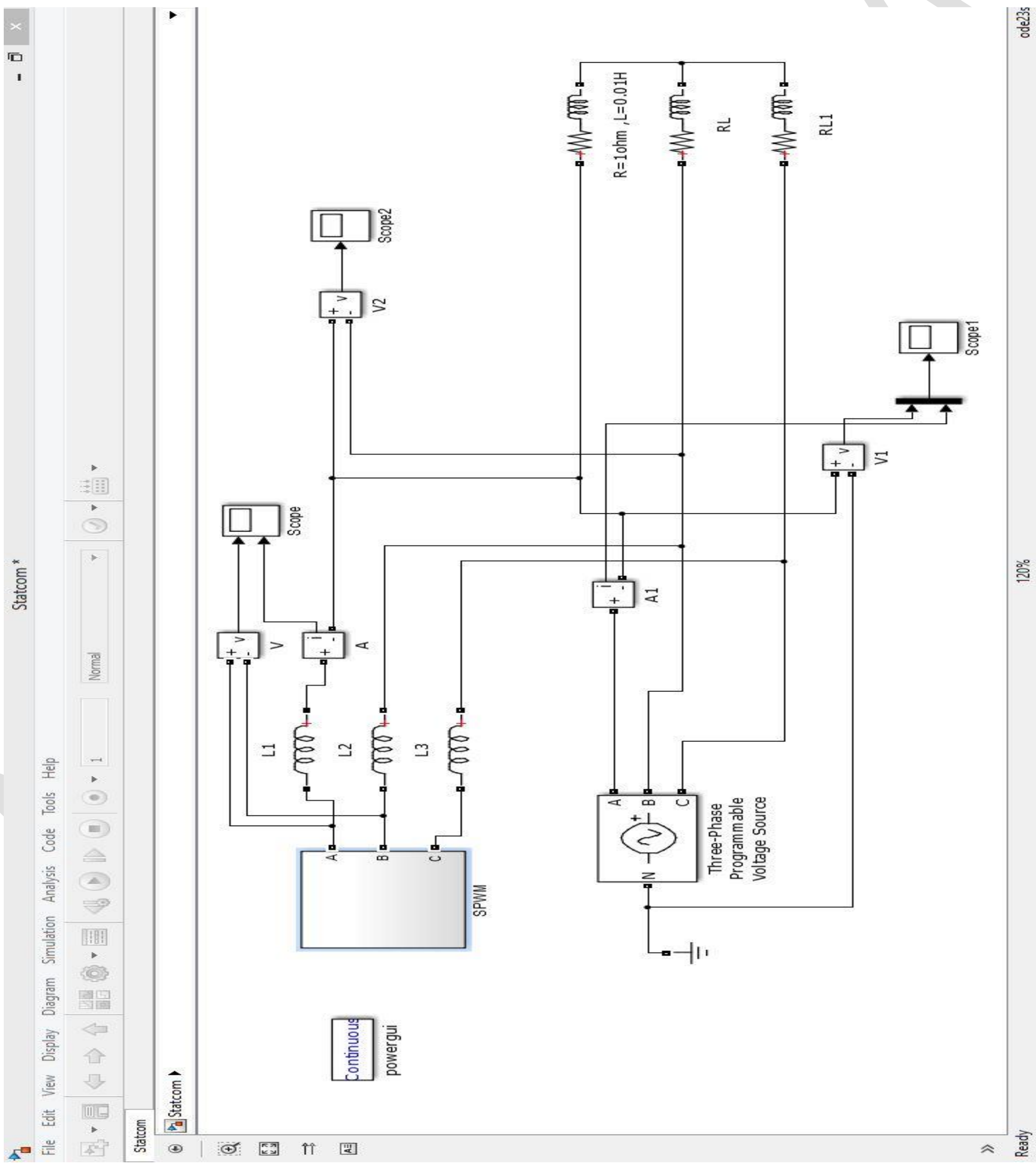

Figure 7: Simulation of D-STATCOM based on Sinusoidal Pulse Width Modulation (SPWM)

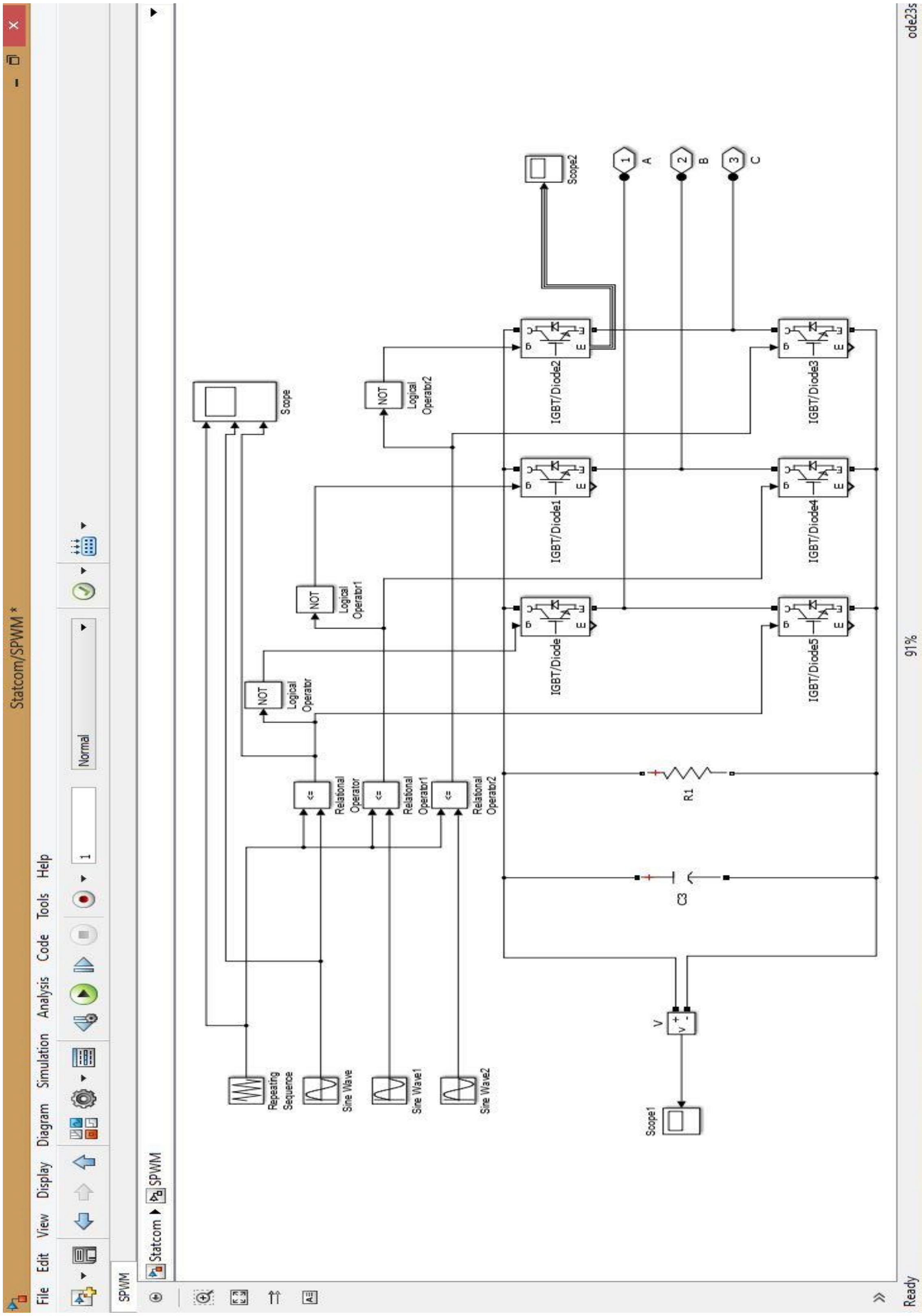

Figure 8: SPWM (Sinusoidal Pulse Width Modulation) Block

3.2 SINUSOIDAL PWM CONTROL IN STATCOM

The basic purpose of using these Sinusoidal PWM control is to keep or control voltage to a steady value at a point where load is there when system is under disturbances. This control system when employed with transmission system measures the rms value of voltage and estimations of reacrive power is not required. The VSC exchanging system is in view of PWM procedure which gives effortlessness and great reaction.

The PI controller procedure recognizes the mistake flag and creates the obliged point δ to drive the blunder value equal to zero, i.e., the heap rms voltage becomes equal to reference voltage. In the PWM generator, the sinusoidal signal $V_{control}$ is thought about against a triangular sign (bearer) to create the exchanging signs from the VSC. Primary parameters of these control system plan are as follows: Amplitude modulation index M_a of signal $V_{control}$, and Frequency modulation index M_f of the triangular sign. The M_a is kept settled at 1 pu.

$$M_a = \frac{V_{control}}{V_{tri}} \qquad (6)$$

Where $V_{control}$ is the maximum value of the signal.

V_{tri} is the maximum of the carrier signal.

The switching frequency is set at 450 Hz. The frequency of modulation index is given by,

$$M_f = \frac{F_s}{F_f} = \frac{450}{50} = 9 \qquad (7)$$

Where M_f is the frequency of modulation index.

F_s is the switching frequency.

F_f is the fundamental frequency.

In this thesis it is assumed that network is balanced and is operated at operating conditions.

3.3 ANALYSIS RESULT OF STATCOM

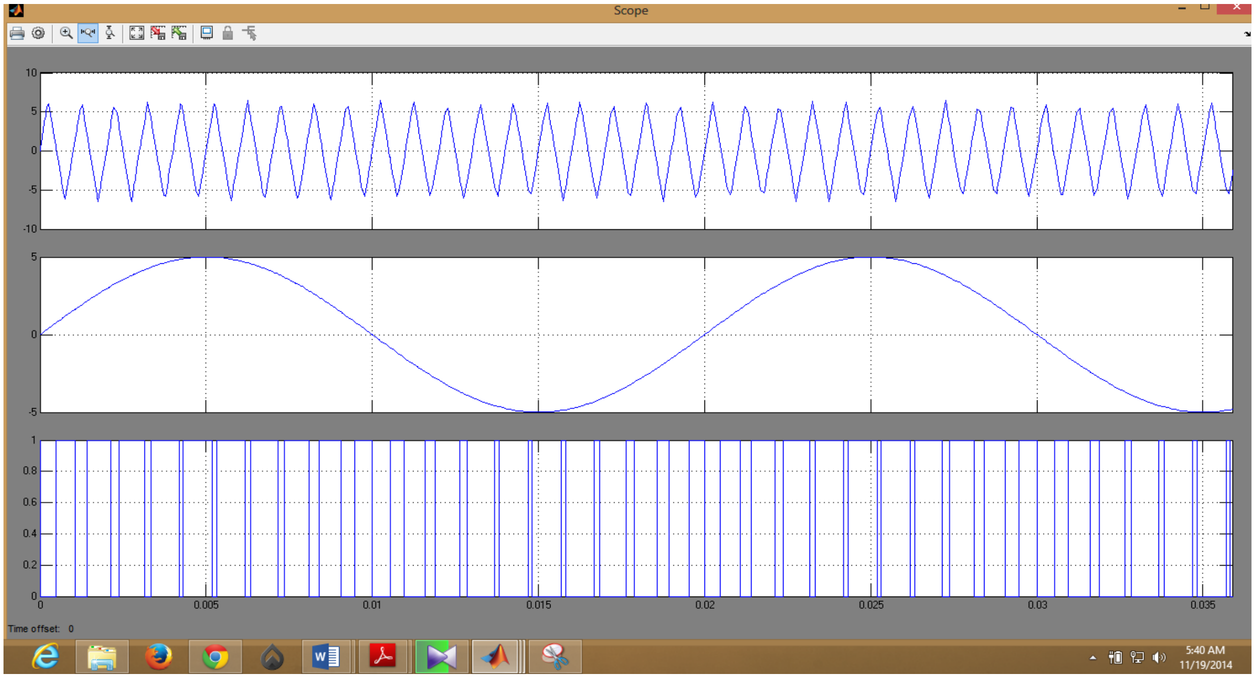

Figure 9: Output of scope in SPWM Block, sine, triangular and square wave generation

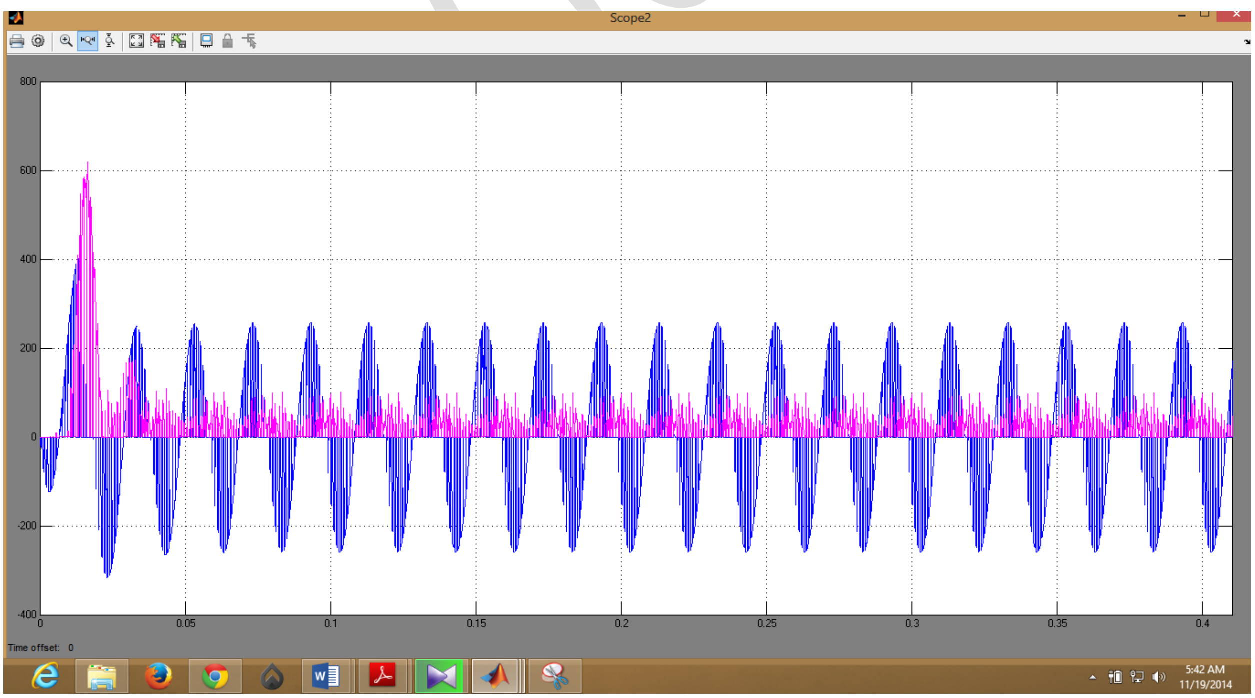

Figure 10: Output of IGBT in SPWM Block

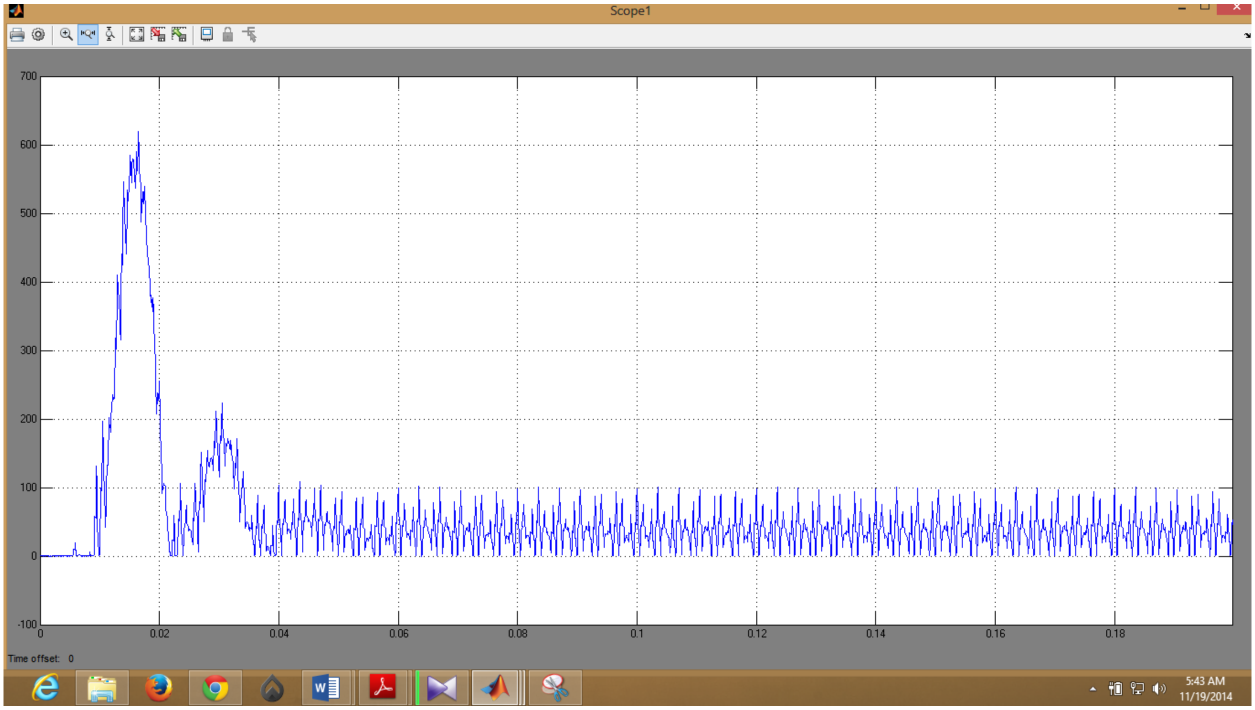

Figure 11: Voltage across capacitor in SPWM Block

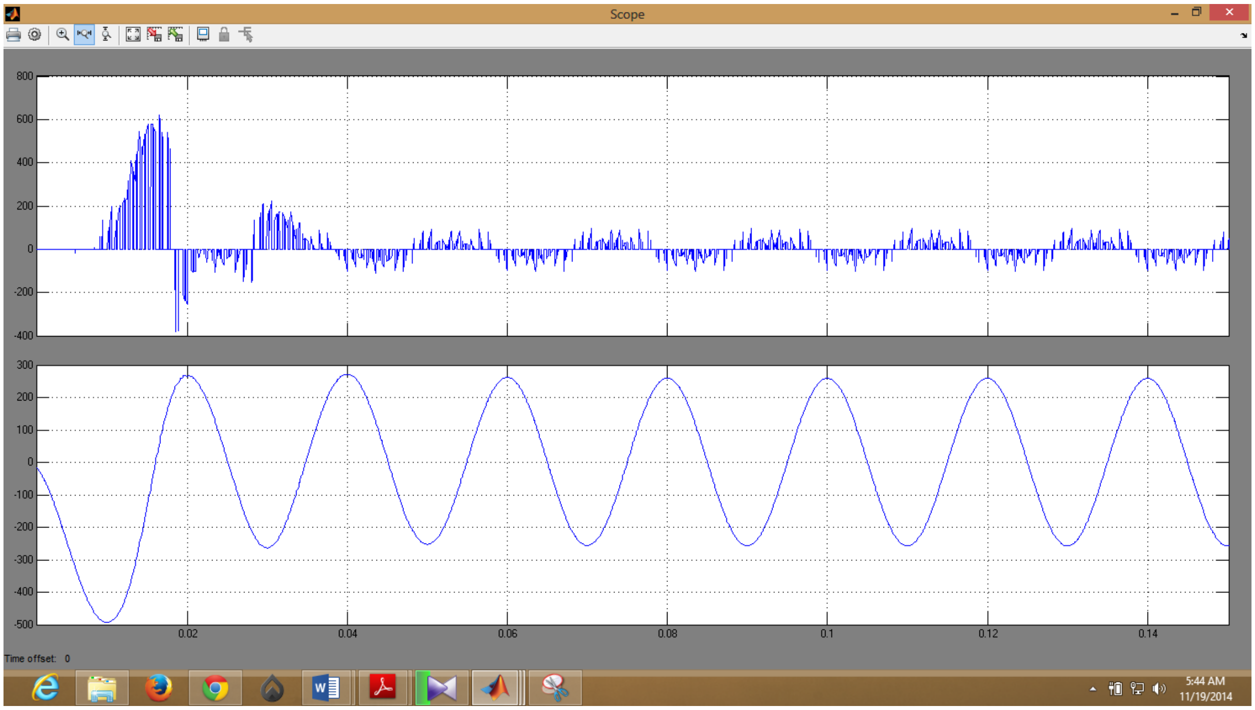

Figure 12: Current Waveform output of STATCOM

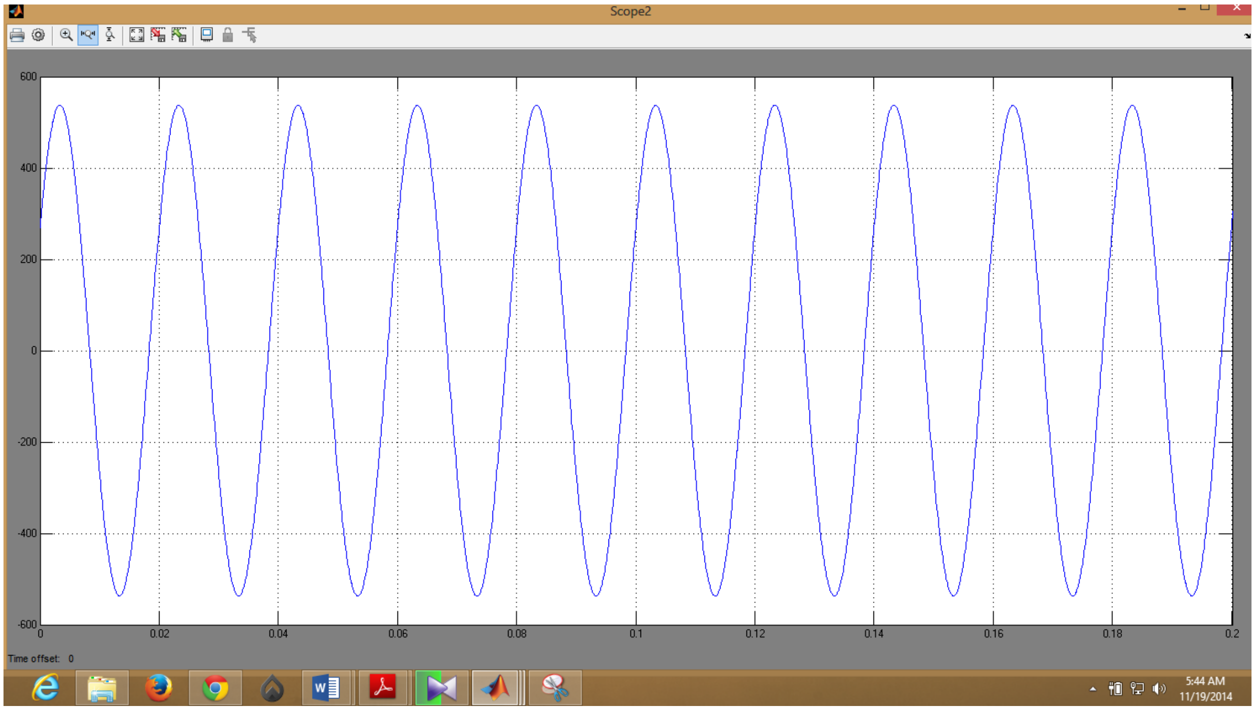

Figure 13: Voltage Waveform output of STATCOM

3.4 ANALYSIS OF SVC IN SIMULINK

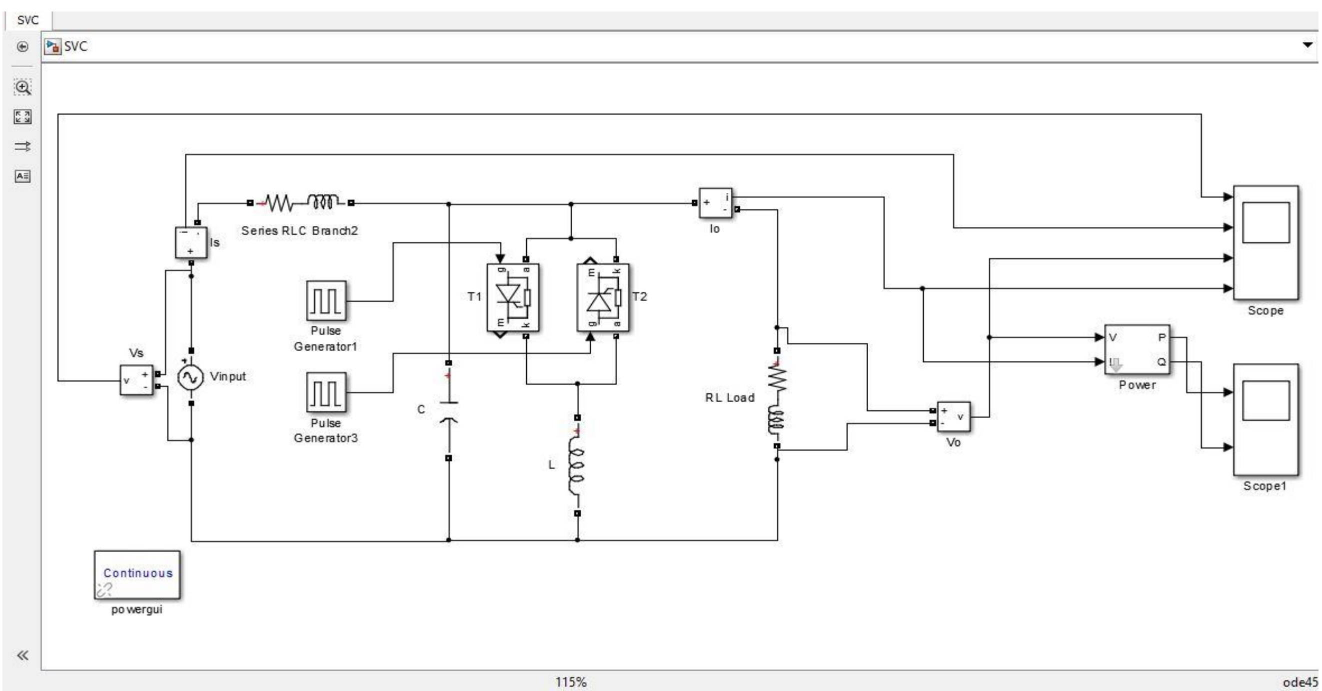

Figure 14: Circuit connection of SVC in Simulink

3.5 ANALYSIS RESULT OF SVC

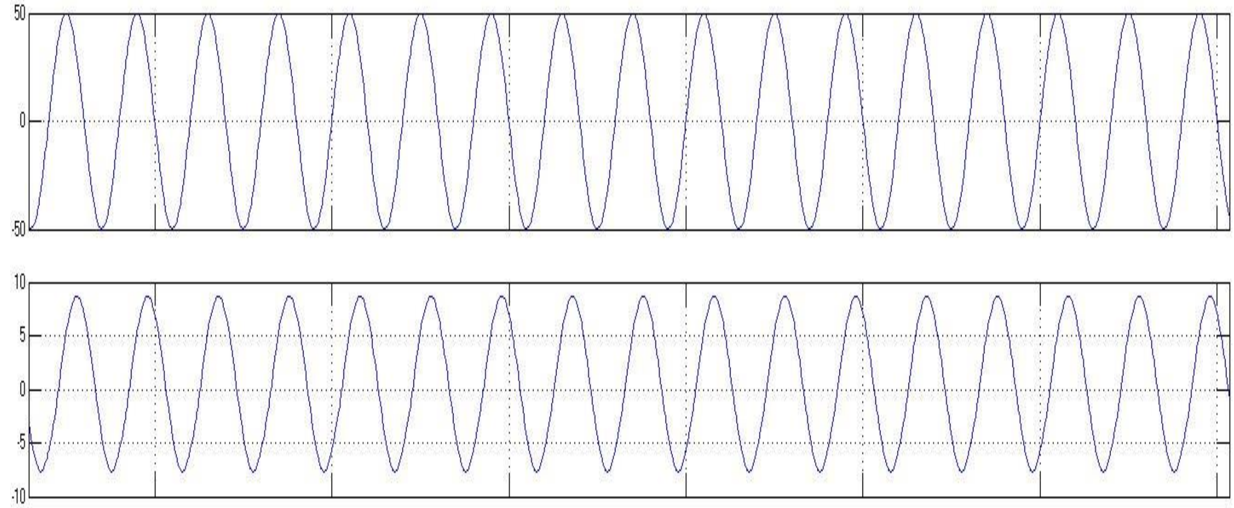

Figure 15: Input voltage and current waveform of SVC circuit

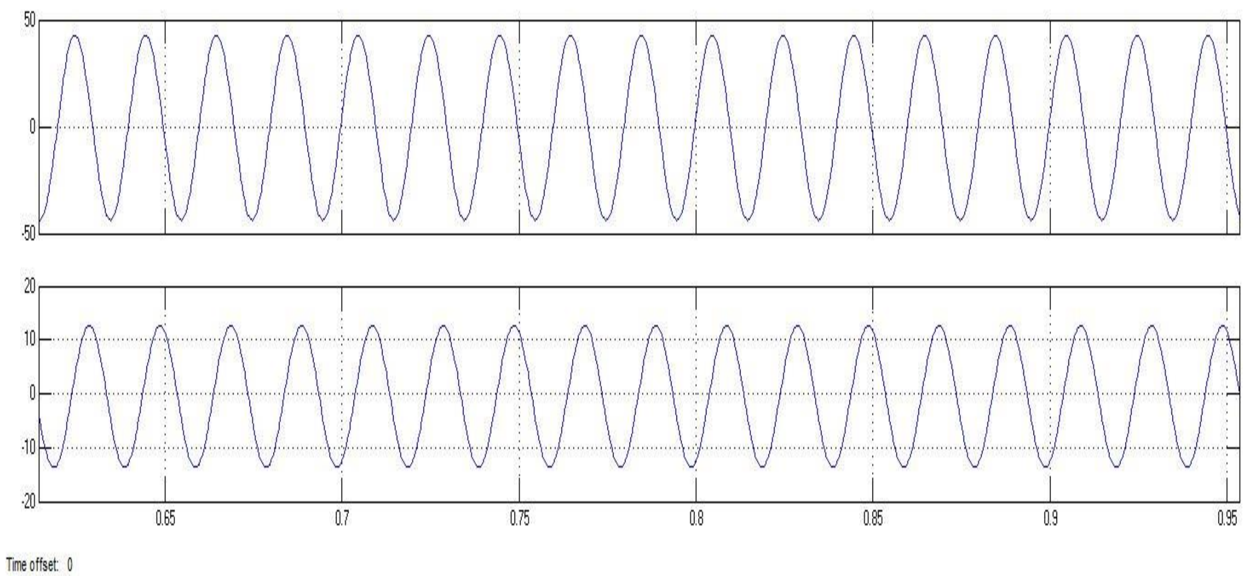

Figure 16: Output voltage and current waveform of SVC circuit

Output of SVC for different inductor and capacitor values can be plotted as following. Following table shows the increment of Q (VAR) while keeping Constant Capacitor and Inductor Varying:

C(mF)	L(mH)	Q(VAR)
200	100	2.4685
200	300	2.4754
200	500	2.4759
200	700	2.4781
200	900	2.4785
200	1100	2.4787
200	1300	2.4791

Table 1: Increment of reactive power when capacitor is constant and inductor is increasing

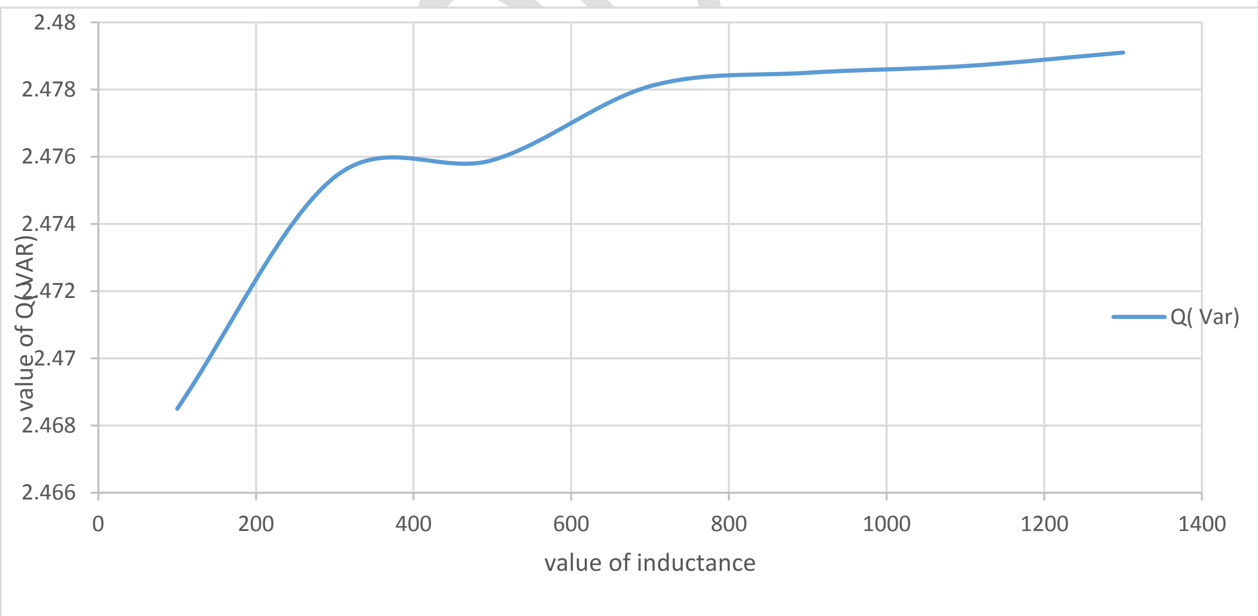

Figure 17: Graph showing the increment of the Q (VAR) value while increasing the Value of the inductor in SVC

Output when Capacitor varying and Inductor constant. Table can be made as follows:

L(mH)	C(mF)	Q(VAR)
100	200	2.4689
100	400	2.4652
100	600	2.4578
100	800	2.4538
100	1000	2.4522
100	1200	2.4458

Table 2: Decrement of reactive power when capacitor is increasing and inductor is kept constant

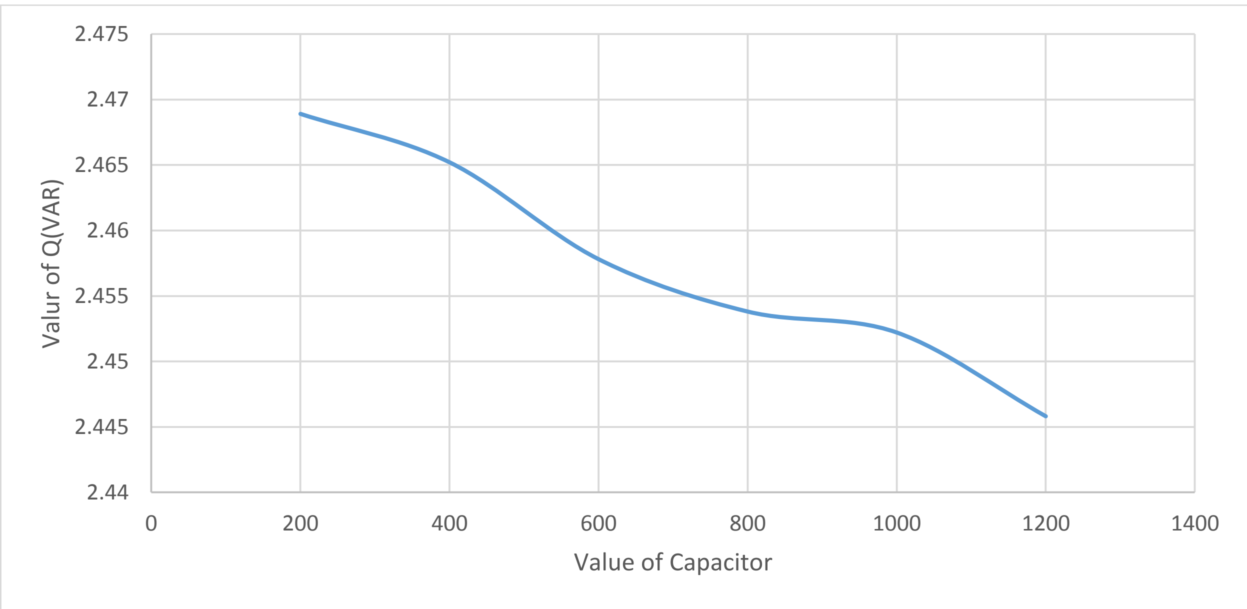

Figure 18: Graph showing the decrement of the Q (VAR) while increasing the Capacitor in SVC

3.6 COMPARISON BETWEEN STATCOM AND SVC

CHARACTERISTICS	STATCOM	SVC
V/I Characteristics	Good performance in under voltage condition	Limited performance in under voltage condition
Response Time	1 to 2 sine wave cycles	2 to 3 sine wave cycles
Installation Size	About 40% to 50% to the size of SVC installation	About 200% to 250% to the size of STATCOM installation
Installation Cost	About 120% to 150% to the cost of SVC installation	About 66% to 83% to the cost of STATCOM installation

Table 3: Comparisons between STATCOM and SVC on the basis of various characteristics

CHAPTER - 4

4. ANALYSIS OF STATCOM FOR THREE PHASE AC SYSTEM

4.1 STATCOM ANALYSIS USING SIMULINK

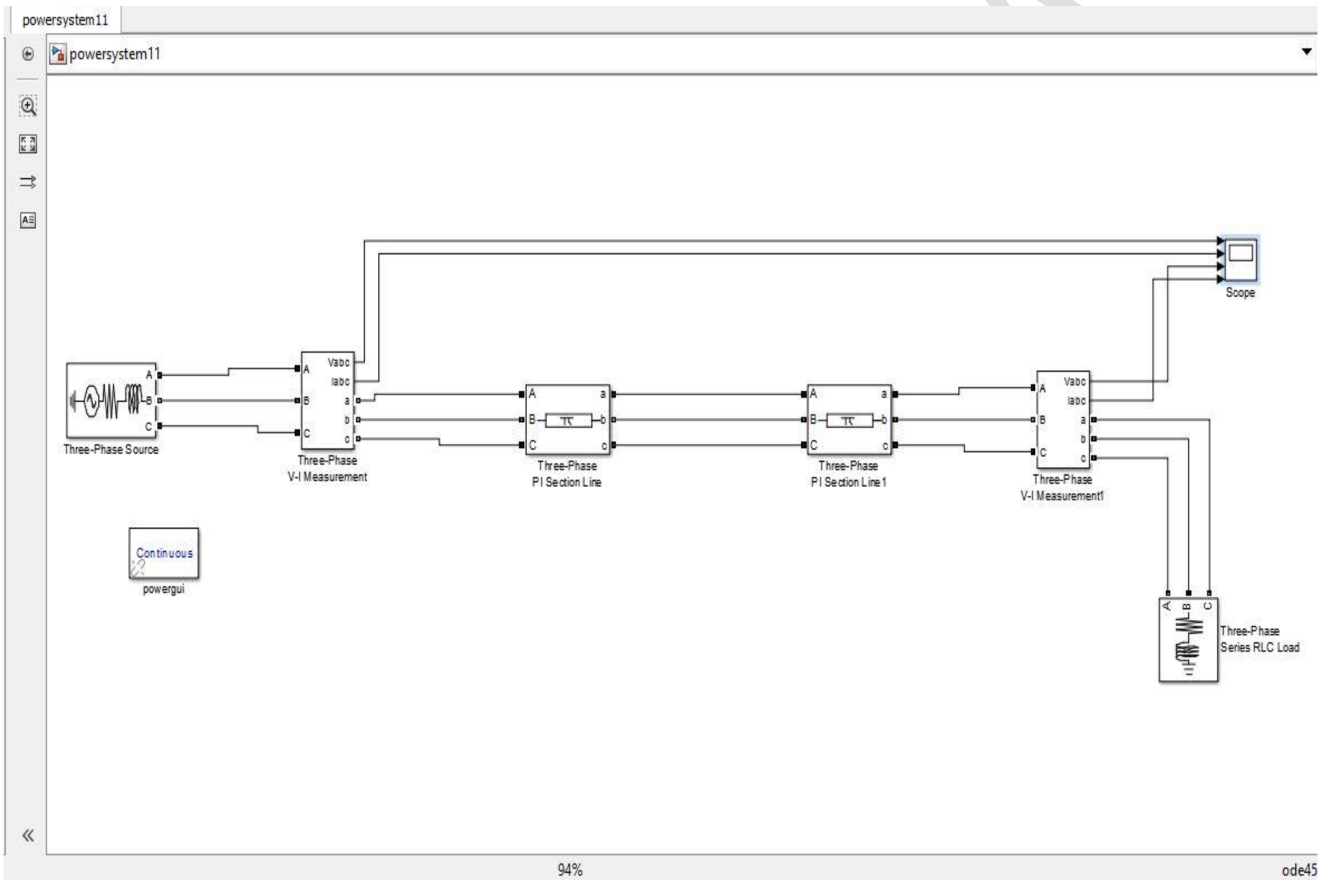

Figure 19: General outline of a power system transmission line

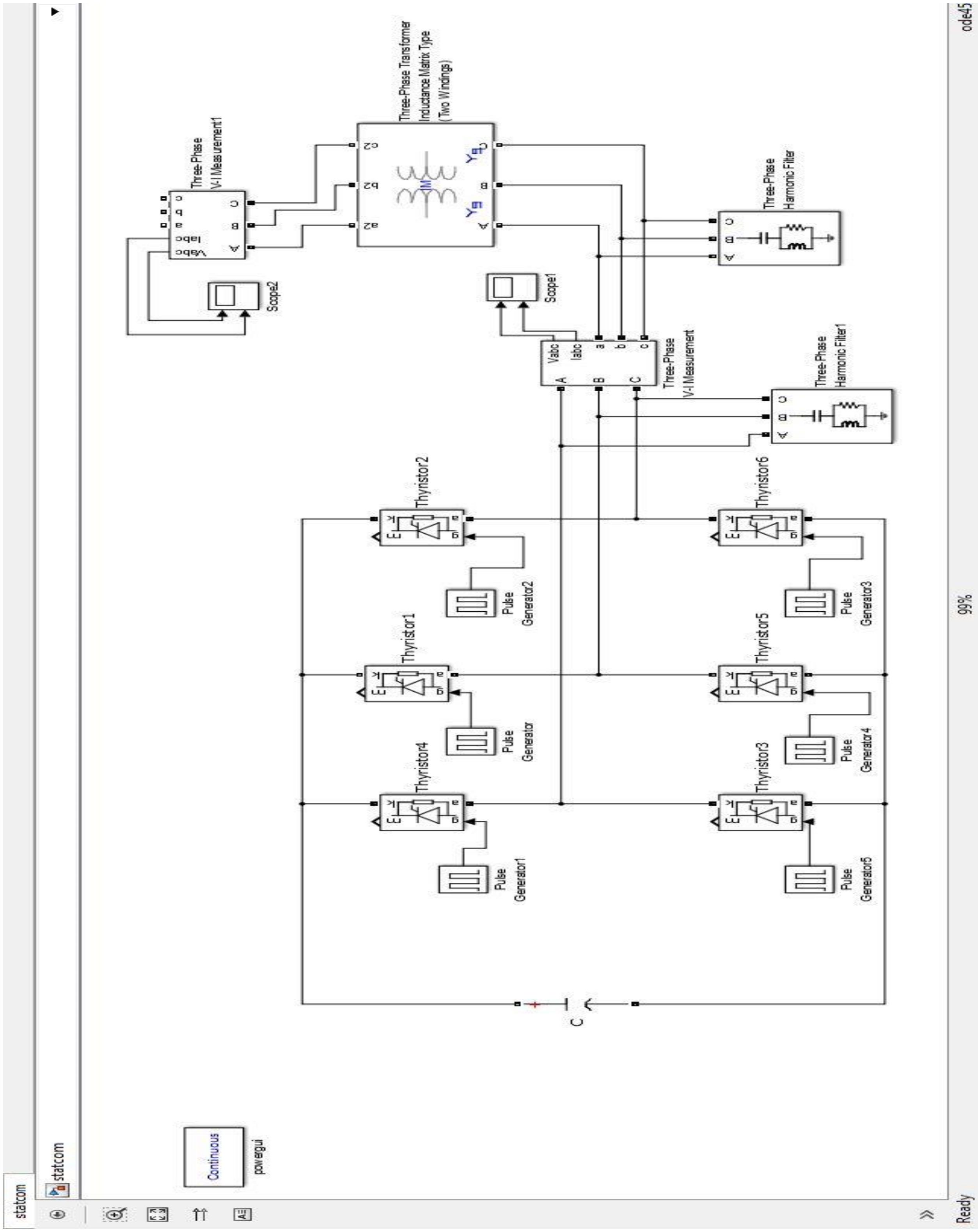

Figure 20: General outline of a STATCOM without connected to transmission line

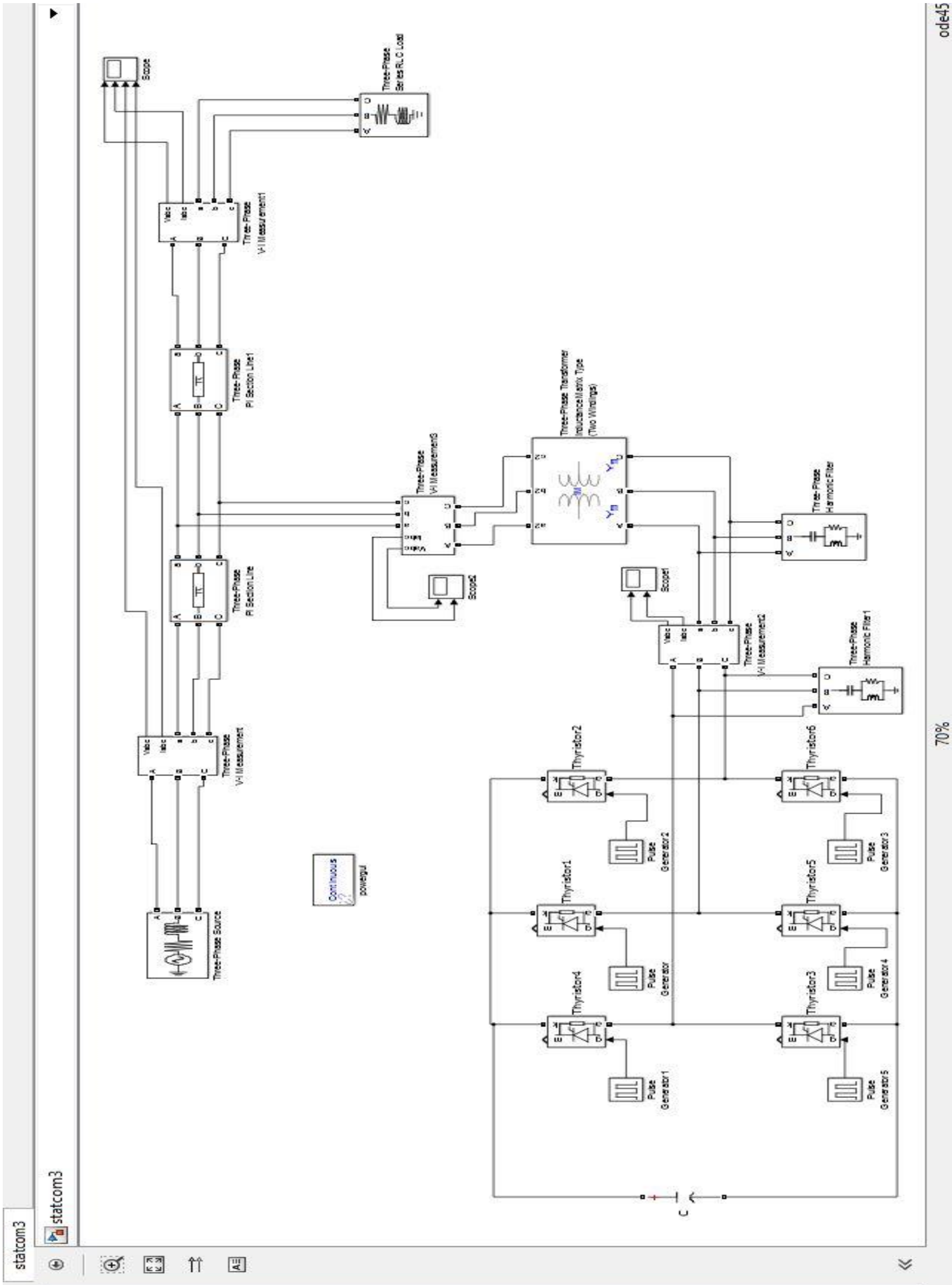

Figure 21: Circuit Model of STATCOM connected to a 3 phase AC transmission line

4.2 ANALYSIS RESULTS

Outputs of AC transmission line when not connected to the STATCOM:

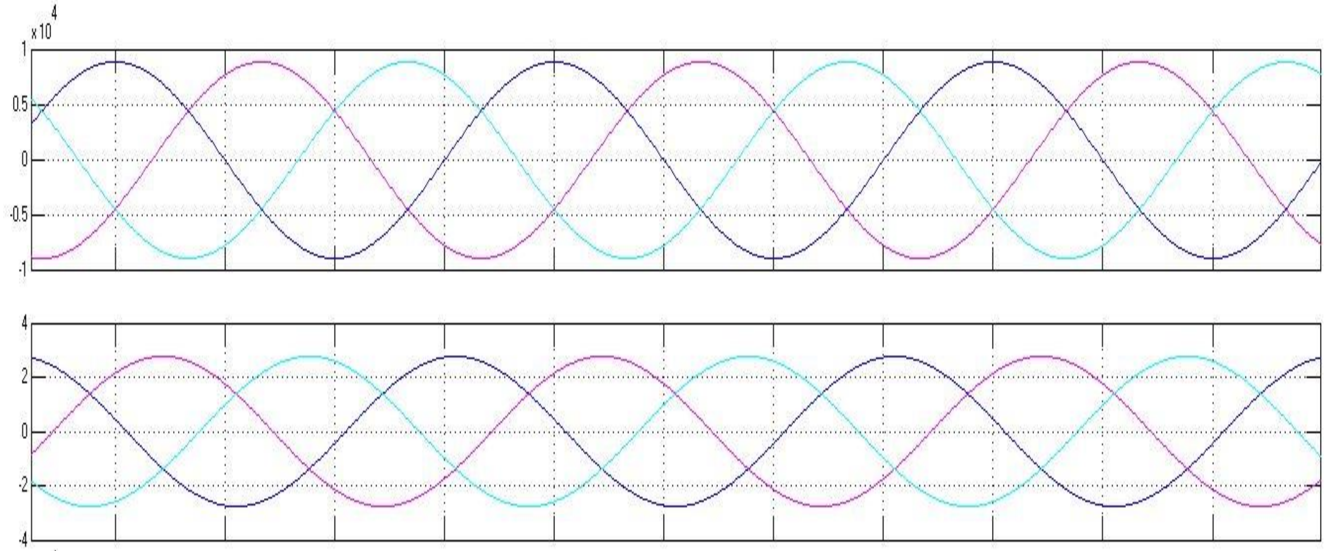

Figure 22: Input voltage and current waveform when load is not connected

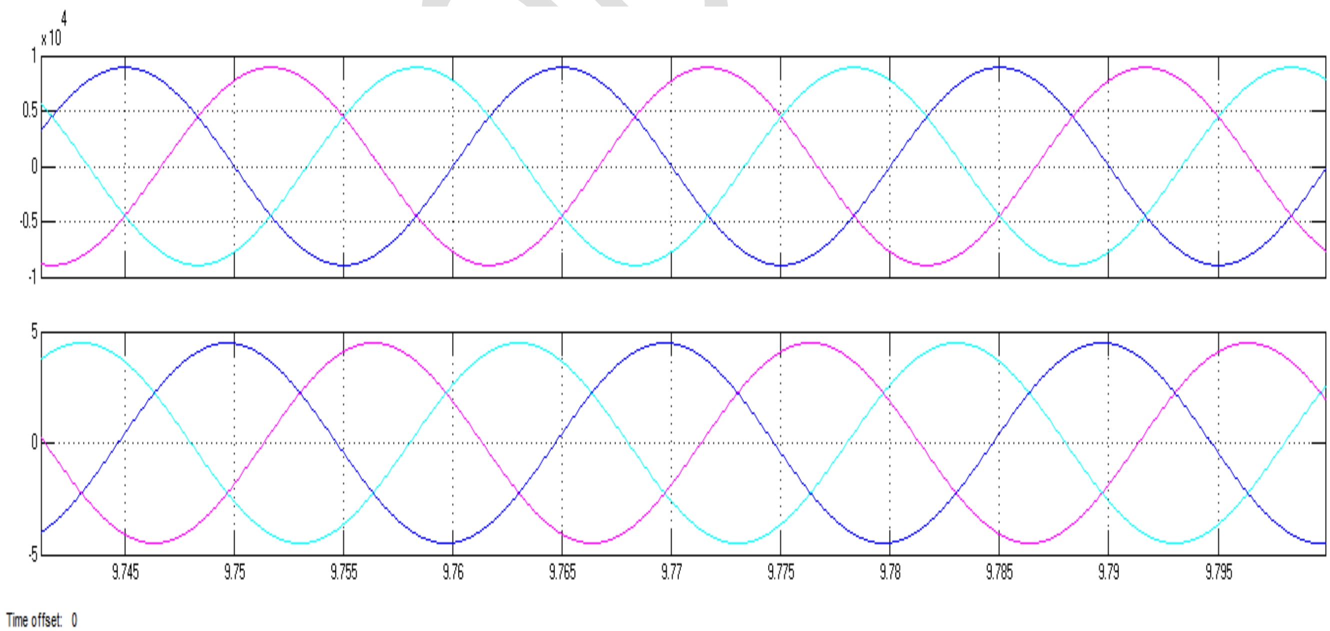

Figure 23: Output voltage and current waveform when load is connected

When we haven't connected STATCOM to the grid, output of statcom is distorted which is shown when we have done simulation of Statcom only without connecting to the grid. Output of Statcom when not connected to the Grid:

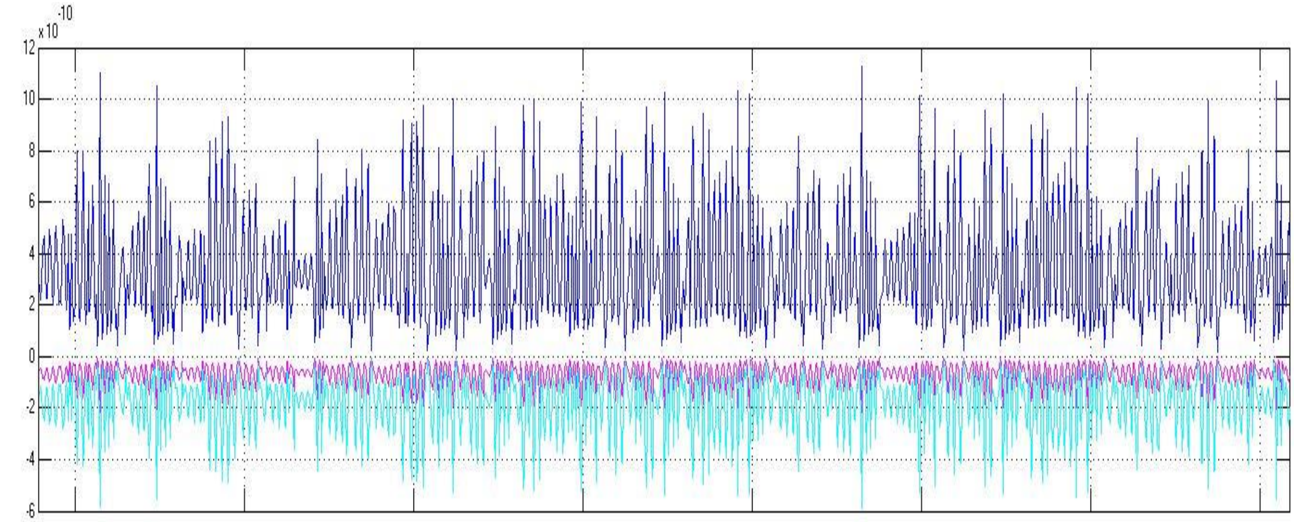

Figure 24: Output voltage waveform of STATCOM when not connected to Grid

After being connected to the Grid, distortion in output is lost and a pure sinusoidal waveform comes. Output of Statcom when connected to the Grid:

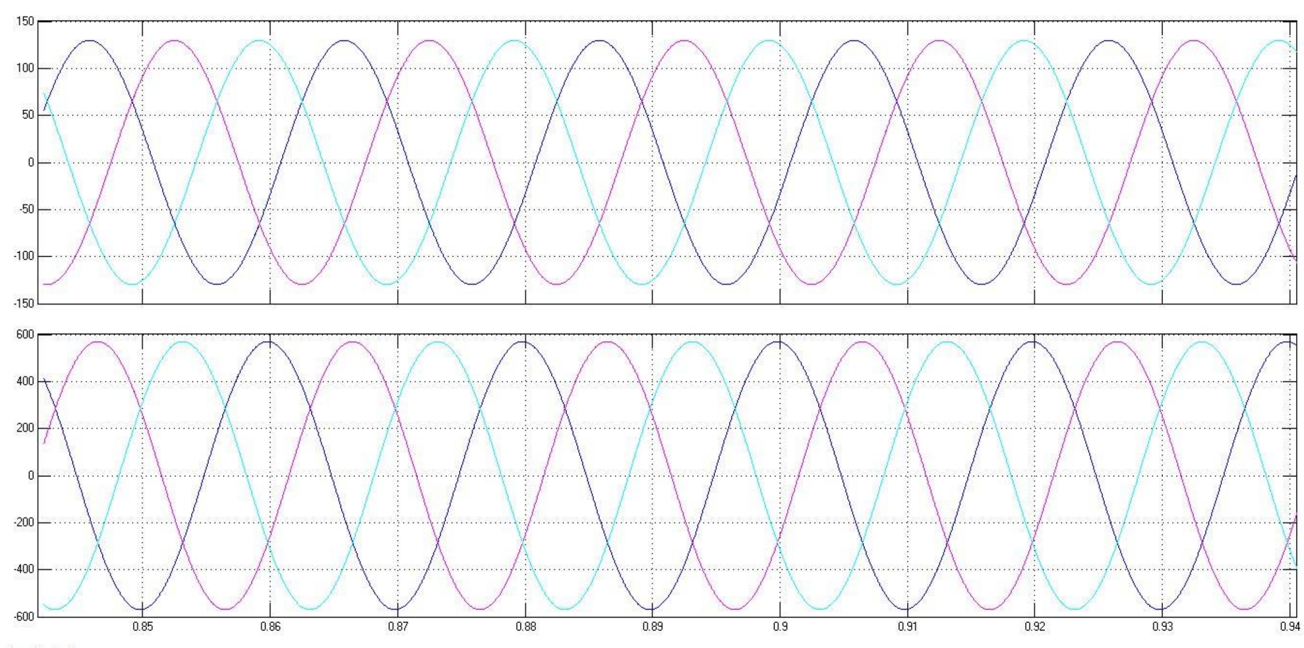

Figure 25: Output voltage and current waveform of STATCOM when connected to Grid

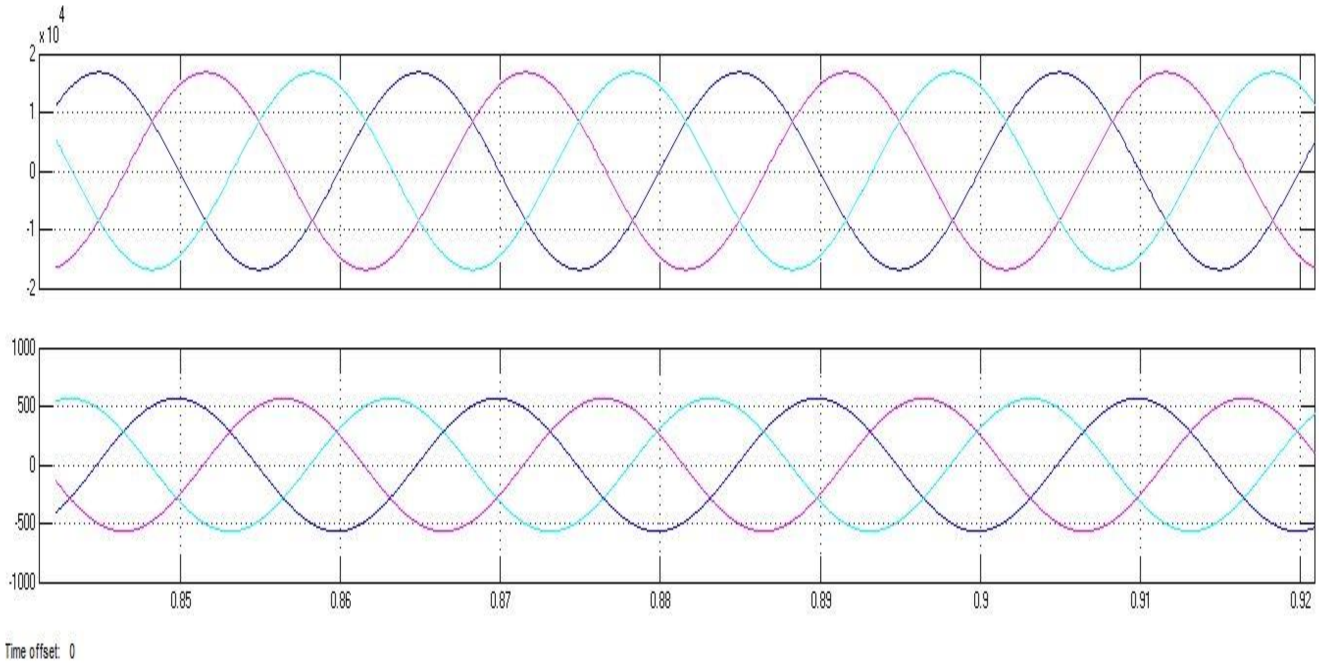

Figure 26: Output voltage and current waveform of AC Transmission Line when STATCOM is connected

CONCLUSION

In this venture the investigation of the essential standards of the STATCOM is done and in addition the fundamentals of reactive power compensation utilizing a STATCOM. This undertaking has displayed the power quality issues, for example, voltage sags and swell. Compensation strategies of custom power electronic gadget D-STATCOM was exhibited. The Voltage Source Convert (VSC) was actualized with the assistance of Sinusoidal Pulse Width Modulation (SPWM). This SPWM is modeled suitably to for D-STATCOM and required analysis was done. A comparision between STATCOM and SVC for single phase transmission line was also formed and it was found that STATCOM gives more for a particular input that SVC. Also the study of reactive power compensation of three phase AC transmission line is also carried by connecting 3-phase STATCOM to transmission line and required analysis is done through Simulink.

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